BELLCOMM, INC.
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SUBJECT: On the Mode of Spacecraft Operation of Long Duration Manned Missions
Case 103

DATE: October 17, 1968

FROM: C. C. Ong

ABSTRACT

There are three basic modes of spacecraft operation which can be applied to a long-duration manned mission. They are, namely, the watch mode, the alert mode, and the sleep mode. A choice among these operational modes will significantly effect the crew requirements of the mission. One of the most important factors which determine the desirability of these modes is the response time of the crewmen required for the corrective actions under each mode in case of a subsystem failure which may lead to a state of emergency.

In this document, the effect of the mode of operation on the crew requirements and the mission safety is assessed by applying the results of the human reaction time studies. It was found that:

(1) the watch mode of operation does not seem to offer any significant advantage over the other two modes,

(2) the alert mode of operation appears to be a reasonable choice for the basic mode of operation, and

(3) it is highly probable that a sleep mode can be applied without great sacrifice on the crew safety and/or mission success.

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SUBJECT: On the Mode of Spacecraft Operation of Long Duration Manned Missions Case 103

DATE: October 17, 1968

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MEMORANDUM FOR FILE

INTRODUCTION

One of the important factors which govern the planning and design of an advanced spacecraft for a long duration manned mission is the minimum crew size required to ensure success. The number of astronauts needed to operate a spacecraft is dependent upon the nature of the specific mission objectives and the design of the space vehicle as well as a large number of other factors. One of these factors of great importance is the mode of operation of the spacecraft, which so far has received little specific attention. Previous studies on manned space stations have generally assumed the continuous watch mode, hence, the four man crew is widely accepted as a design criterion as the minimum for long duration operations.

In scheduling the work/rest cycles for the crew members, different modes of operational control can be selected. Most investigators of long duration missions have argued that at least one of the crew members should be scheduled to stay with the control console at all times; whereas in past short duration experience all the astronauts in a spacecraft have been allowed to sleep at the same time. Without doubt, the desirability of these modes will depend to a great extent upon the advancements of the aerospace technology in the near future, and the selection of modes will have a profound impact on the feasible crew size. There are, however, two fundamental requirements: safety of the crew, and a high probability of mission success. In this study, these two basic issues will receive the primary concern when the relative merits of the various possible modes of operation are assessed. Only the spacecraft operations in the normal cruising phases of a long duration mission will be considered; specific requirements for earth-orbit launch, landing on a planet, earth re-entry or any other critical, short duration, mission phases will not be emphasized here. The projected spacecrafts are assumed to be automatically controlled under normal conditions with the astronauts needed only for the scheduled management and maintenance and in the event of subsystem malfunction or other emergency. It is the response of the astronauts during such a contingency that is the center of our attention in this investigation.

APPROACHES TO SPACECRAFT OPERATION

One of the most critical activities of the crew members in spacecraft operations is to respond to a system malfunction which may lead to an emergency. The task of failure detection can be performed either by a man or by a machine; the relative capabilities and limitations of man and machine when performing this task have been discussed in great detail in Reference 1. Both man and machine are capable of detecting and discriminating many forms of physical energy. In one instance, man may be required to perform the task because of his multipotentiality for sensing physical energies and his unique ability of making judgements. Where detection would be monotonous, hazardous, inefficient, or impossible for man to perform, equipment sensors are required or desired. A survey of current technologies reveals that we can reasonably assume that an automatic failure detection and warning system capable of monitoring all the important system performance and environmental parameters will become a standard equipment in all the future manned spacecrafts. Our main concern here is the manner in which action is taken by the crew member.

There are, basically, three different modes of operational control which can be applied in manning a spacecraft. They are:

(1) Watch mode -- At least one crew member shall be assigned to man the control console at all times, so that he can be readily on hand in case of emergency to take proper actions that are called upon by the situation.

(2) Alert mode -- At least one crew member shall be kept awake at all times. He may or may not be assigned to any duty; but he shall be alert at all times.

(3) Sleep mode -- All the crew members are allowed to sleep at the same time; they will be awakened by an audio warning signal in case of system failures or malfunctions which may threaten mission success or safety of the crew.

EFFECTS OF MODE OF OPERATION ON CREW REQUIREMENTS

The crew requirements reported in previous studies of advanced manned mission have been largely based on the concept that a number of crewmen have to be awake at all times. A Boeing report on Saturn V Single Launch Space Station and Observatory Facility[2] specified that, in a space station manned by a six-man crew, at least two crewmen were needed to be awake at all times; they might or might not be assigned to the duty of manning the control console. A Douglas report on study of Manned Mars Exploration[3] decided upon a six-man work/rest cycle in which two crewmen were assigned to command control duty at all times. The duties which must be performed at the command post include management functions, vigilance monitoring and data handling. The presence of two crew members permitted an exchange in control and the temporary absence of one. In another Douglas report on the optimization of the Manned Orbital Research Laboratory (MORL) System Concept[4], the following ground rules for the normal operation of the spacecraft in the mission orbital phase were established:

(1) at least two crewmen must be awake and available for duty at all times, and

(2) one man must be available for station management at all times; yet he did not have to give this operation his undivided attention.

A work/rest schedule, based on the third mode of operation, namely, the sleep mode, has yet to appear in the literature. The basic reasons which have prevented the selection of this approach are considered to be the following:

(1) A sleep mode of operation may greatly reduce the crew safety and/or the probability of mission success in case of emergency. This will primarily be caused by the delay of responsive actions due to degradation of human performance upon sudden awakening from sleep.

(2) The minimum crew size is, sometimes, governed by the requirements in a critical mission phase, such as Mars exploration; therefore, a large number of crew-men are available for normal operation in which the economy of manpower that a sleep mode can offer is deemed unnecessary.

The Boeing Study[2] previously mentioned indicated that for an earth orbiting space station designed to accomodate a six-man crew and a two-year mission, the total time required for station management was about 4 man-hours per 24 hour period. The Douglas Study on MORL[4] reported that the average time required to operate the station in its orbital phase was about 5 man-hours per day. Based on these estimates, a watch mode of operation results in up to 20 man-hours per day devoted to vigilance monitoring only. On the other hand, if a sleep or an alert mode is applied, these 20 man-hours could be fully or partially utilized for other crew functions. In a sleep mode, the time relieved from operational control can be utilized for any crew functions inside of the spacecraft, whereas in an alert mode, this time can only be scheduled for activities other than sleep (see Figure 1.) Therefore, the former provides additional flexibility to the scheduling of crew functions. Assuming that all crew members work 10 hours in every 24 hour period, the application of an alert or sleep mode of operation could result in a maximum reduction of 2 crewmen from the requirement of a watch mode.

A comparison of the relative effects of the operational modes on several important crew requirements is given in Table 1. It is obvious that, in addition to the smaller number of crew needed for the operational control, an application of the sleep mode of operation will save crew training and result in more freedom to evolve operators work/rest schedule. It should be pointed out that while a sleep mode is preferred over an alert mode so far as the interaction between the spacecraft control and the experiments are concerned, it's actual advantages on freedom of work/rest schedule and the crew training remain to be explored.

HUMAN RESPONSE TIME

The human reaction time upon receiving an external stimulus and the capability of performing certain tasks in various stages of alertness, expecially upon sudden awakening from sleep, are the most important factors which must be considered in reviewing the relative merits of the various modes of operation regarding the crew safety and mission success.

1. Normal Reaction Time[5,6]

The time required to respond to a certain signal depends upon the characteristics of the signal, the sense used, the complexity of the signal, the signal rate, the alertness of the subject and a large number of other factors. When a subject is fully alert, a decisive factor on the reaction time will be the complexity of the signals. Whether a reaction is named simple or complex depends on the nature of the decisions the subject must make in responding to the signals.

a) A simple reaction is a predetermined response to a given stimulus, such as pressing a button after perceiving a stimulus for which no choice among alternate responses is required. The average reaction time for this type of reaction is about

0.20 to 0.30 seconds, varying with the senses involved. Even an extremely slow person, barring physical disability, can usually start a physical movement within 0.5 second after a signal is given. The mean value and the range of the simple reaction time are shown in Table 2. It should be pointed out that these data were gathered under laboratory controlled conditions and hence, are minimal; at least 0.5 additional second might be expected under working conditions[5].

b) A complex reaction involves a decision between two or more possible signal-response combinations, such as responding to one of several numbered signal lights by pushing a similarly numbered button. As the number of combinations increases, the time required to respond to any one signal also increases, as shown in Table 3. These data were collected under such conditions that the operator was well practiced and motivated. Reaction time under working conditions might be 1 to 2 seconds longer than the values given by the Table, depending on the number and complexity of the choices and the experience of the individual[5]. A simple formula was given by Hick in 1952[7] to determine the complex reaction time, which can be expressed as

$$T_r = C \log_{10} (n+1) + T_m \quad \text{(in seconds)}$$

where T_r is the reaction time, n is the number of choices, C is a constant, and T_m is the movement time. For completely discriminable signals and ungraded responses, C will vary from 0.5 to 0.65.

2. Human Performance in Watchkeeping

Within the scope of the present study, the word watchkeeping is simply defined as a task in which the operator monitors the status of the spacecraft through a visual display, and is required to respond to signals that might occur at any time during the watch; and most of the watch period is devoid of incidents and demands for action. When the signals appear infrequently, the task is called a vigilance task. Studies of vigilance problems have indicated that long watch periods are harmful, that is to say, the longer the watch period, the more likely that some signals will be missed, and, when signals are detected, response times will be long. When working conditions are good, an operator might be able to continue for a number of hours without serious vigilance decrement.

There is a widespread belief that continuous, monotonous visual search produces a condition akin to hypnotic sleep[8]. It can be established in the laboratory that observers may lose vigilance beyond the point of voluntary recovery, namely, no matter how hard they try, they cannot increase their attentiveness to the signals being searched for.

It is known that the human waking center in the hypothalamus must be maintained at a high excitatory level by continued sensory input. Any reduction in the sensory input characteristic of monotonous search may reduce the excitability of this or analogous centers in the control of the activity of the organism and, consequently, contribute to the decline of vigilance and to an inability of the observer to recover vigilance voluntarily.[8]

Therefore, the operator should not be isolated from other people nor deprived entirely of incidental stimulations, such as eating or minor interruptions, that is to say, he need not give the operation his undivided attention. His performance can be greatly improved by allowing a short period of rest, say, 5 minutes every half an hour. A typical example of performance on a difficult vigilance task with and without rest periods is shown in Figure 2.[6] In order to provide a margin of safety, it is possible that an audio alarm system should be used in parallel with the visual display even when an operator is required to stay at the control panel under the watch mode of operation. It is common practice to employ a warning horn in aircraft to indicate a failure to lower the landing gear and audio stall warning devices even though adequate visual indicators are present.

3. Reaction Time and Performance Upon Sudden Awakening From Sleep

The problem of human response to a stimulus immediately after being aroused from sleep and the effectiveness of his performance have received only scant attention in the past; little conclusive information can be obtained from literature. However, recent research in this area does provide some quantitative results which are pertinent to the problems involved in the present study.

Langdon and Hartman (1961)[9] reported an experiment in which the human performance upon sudden awakening from sleep was observed. The experiment consisted of awakening five subjects, individually, from 2 to 8 hours of sleep by turning on the bedroom light and shaking the subject. The subject was then hurried to perform a well practiced system-type psychomotor task, utilizing the complex behavior simulator. All tasks involved discrete signals, such as a light flashing on, and simple, discrete responses, such as operating a toggle switch which could turn the light off. Performance was evaluated in terms of average response time on a minute-by-minute basis after awakening, as shown graphically in Figure 3. The response time on the first few minutes was approximately 20-30% longer than the presleep values. Progressive recovery was noticed during the ten minutes performance. It should be added that the proficiency on the tenth minute did not reach the presleep levels, and there was no report on the time required for a full recovery.

It is interesting to note at this point that in a series of Russian studies, Vasilev and colleagues[10] found that the mean values for peak muscle strength and sustained muscle strength were lower at night than at daytime; but in the 45 minutes period between awakening at night and performing a 5 km skiing race, the muscular strength, body temperature, and pulse rates had risen to daytime levels. This result implied that 45 minutes would be more than enough to recover from sleep if vigorous physical activities were continued during this period.

Langdon and Hartman also pointed out that misjudgment may occur in performing complex tasks upon sudden awakening from sleep. For example, at one base of the Air Defense Command, pilots were allowed to sleep on alert duty and were expected to be air borne within 2 minutes after a "scramble" alarm was sounded. A crash occurred during take off on such a scramble due to numerous errors made by the pilot awakened from a deep sleep. As a result of this accident, although sudden awakening was not proved to be a factor, all alert pilots in ADC were subsequently required to stay awake.

Webb and Agnew (1964)[11] studied the reaction time immediately after being aroused from a short period of afternoon sleep when either a stage 4 or a 3-hour period sleep was reached. Twelve subjects were tested, both before and after the sleep; they were requested to respond to the stimuli by pressing the 4 numbered switches in the same order as the 4 numbers signaled on a display panel. In each test, the subject was given five different sequences with a 10-second interval between them. The discrimination reaction time measured was derived from the time the number sequence started showing on the panel to the first key depression of the series, and serial task time was measured from the first key depression in the sequence to the last. The averages of these measurements are presented in Figure 4. It can be seen that for serial tasks, complete recovery occured in about 60 seconds on the average, whereas for a discrimination reaction a rapid recovery was occuring in the first 30 seconds, but failed to reach the pre-sleep levels at the end of the first 60 seconds upon arousal. The average reaction time during the first 60 seconds was about 25-30% longer than the pre-sleep levels in both cases.

Probably the most comprehensive, experimental study concerning this problem is the very recent work conducted by J. Scott of the National Institutes of Health,[12] where a large number of subjects, both men and women, have been tested for their reactions to audio signals during sleep, for the reaction time immediately after awakening as well as for the process of recovery from sleep. In each test, the subject slept in a bed with a bell and a switch installed on its headboard, and was instructed to press the button immediately upon arousal by the bell. This action would turn off the bell and turn on a display simultaneously. There were four numbers on the display, ranging from 0 to 9, two in red and two in white. The subject's subsequent task was to calculate the difference between the sum of the two numbers in red and the sum of the two in white. Some of the unpublished experimental results obtained by Scott are shown in Figures 5 to 7.

Figure 5 gave the average reaction time beginning from the onset of the bell until it was turned off by the subject upon awakening. It was noted that the deeper sleep stage the subject was in before awakening, the slower the reactive motion would be, despite the fact that the time required to start the first muscle movement varied only slightly among different stages of sleep. The total reaction times immediately after arousal from a stage 3 or stage 4 sleep were about 4 times as much as the values taken before sleep, and, when awakened from these deep stages of sleep, the female (♀) subjects showed a better performance than their male (♂) counterparts.

Figure 6 gave the average and the .95% confidence range of the problem-solution time immediately after awakening. These solution times varied widely among individuals after a stage 4 sleep, and in the worst case, it could be as much as 6 times the solution time needed when the subjects were in their normal awake state.

Figure 7 showed the process of recovery. A, B, C, D and E indicated a sequence of tests with an approximate 30 second time interval between them. A was the first test immediately upon awakening. It was clearly shown that the performance was very poor in the first 45 seconds or so after arousal from a stage 3 or 4 sleep. At the end of this period, the performance had been improved by the rapid recovery to within 30% difference from the normal reaction times. And from then on, the pace of recovery slowed down for at least the next 2 minutes or so. It was unfortunate that the sequence of tests was not carried farther to reach the time of full recovery.

It should be pointed out here that the experiments discussed above are all conducted on the ground. There was no information concerning the applicability of these results to astronauts confined in a spacecraft of limited volume and in a state of weightlessness for a long period of time. However, earlier studies[13] indicated that no serious decrements in performance would be expected to result from the restricted spacecraft volume, as long as the limit of the volume does not interfere with the crew mobility. While some adverse effects had been predicted for a person in a weightless state; for instance, physiological degradation was indicated in some body systems and certain tasks might be difficult to perform because of the decrease of muscle strength, it is conceivable that many of the problems created by such situations could be solved by thoughtful design. Therefore, for the purpose of present study the results of the ground based reaction time studies shall be considered applicable to the astronauts in their long duration mission, and the implication of these results can be summarized as the following:

a) Normal reaction time to external stimuli depends, among other factors, the complexity of the signals. Simple reactions take less than one second, whereas, reactions of a relatively more complex nature may take three to four seconds under certain working conditions.

b) Monitoring is a monotonous task. A person sitting in front of a display panel might be in a state of incipient sleep. Therefore, an audio warning system is desirable regardless of the mode of operation to be applied.

c) When a person is aroused from sleep, the time required to perform a simple task of physical motion, such as to press a button, is about three to four seconds.

d) Duties which require a hurried high level of judgement and accuracy should not be undertaken by a person who has just awakened. A recovery time of at least 60 seconds should be allowed after awakening before he can be trusted to perform such tasks.

e) A rapid recovery occurs during the first 60 seconds upon awakening from sleep, and then, the pace of recovery slows down. A degradation of 20-30% in terms

> of reaction time would be sustained for as long as 10 minutes after arousal; and a full recovery within 10 to 45 minutes can reasonably be assumed.

It is perhaps useful to mention here some practical experiences the Navy Department had acquired in the crew emergency response. R. Ditts of NAV Ships Organization[14] observed that the crew of a large ship could be expected to be battle-ready about three minutes after the call for general quarters was sounded. In fact, four minutes is a readily achievable number even for very large ships. Many of the crew members in this exercise were asleep at the time when the call for general quarters was sounded. He felt that, in general, a margin of five minutes is more than adequate to be operational after awakening from a deep sleep.

4. Mobility in the Zero-Gravity Environment

The accumulated experiences of the astronauts in addition to the information resulting from the extensive research on simulated weightlessness indicated that, with adequate training, an astronaut can move in a spacecraft under zero-g environment with a speed comparable to that on the ground. While a maximum speed of 10 ft/sec[15] may be obtainable, some problems involved in the motion of this high speed such as deceleration remain to be solved; and a practical upper limit of 3 ft/sec would be a reasonable estimate. Based on this figure, it is felt that when a sleep mode or an alert mode of operation is applied, a one minute response time would be more than enough for an astronaut to move to the control console from any position in a spacecraft with the size comparable to the proposed Saturn V Launched Orbital Workshop B in the events of emergency.

TYPICAL SYSTEMS

There is very little valid information known on the physiological and phychological effects of the human emotions such as anxiety, fear and fatigue which might be experienced by the crew members during emergencies on a long duration flight under a weightless condition. Caution, therefore, must be exercised in developing man-machine relationships. An ideal design policy would be that, in vehicle emergency operation, machines are used to detect, diagnose and isolate any system malfunction or failure while men are needed only to respond to these signals with decisions and actions.

As mentioned previously, the selection and the design of the instrumentation system used for fault detection, station-monitoring and, particularly for automatic fault-isolation and analysis, would be an ambitious task. In this present study, only the subsystem of fault detection and a display and warning subsystem of the previously mentioned instrumentation system are assumed to be basically automatically controlled and automatically processed. In operation, the performance of all the critical systems will be monitored by the equipment sensors and a full-time display-and-alarm system would be employed for alerting the crew if any critical subsystem should malfunction. A two-stage alarm system will be used in which the fault logic contains 2 thresholds: (1) "Emergency," and (2) "Danger." The "Emergency" audio signals order all the crew members to enter the storm shelter airlock before any other corrective action may be taken whereas the "Danger" audio signals instruct the crewmen to get to the station control center as fast as possible for immediate situation assessment. The term "storm shelter airlock" here indicates and isolated compartment which has a separate environment, status display, and an exit through which the astronauts can enter the reentry vehicle. With this design, the immediate safety of the crew members remains the same in case of emergency, whatever the mode of operation is to be applied; because the difference of time required to enter the storm shelter between the crewmen who is awake and the one being awakened from sleep would only be a few seconds. On the other hand, the effect of the mode of operation on the overall mission safety needs to be studied, because there is a possibility that relatively large differences exist among various modes of operation concerning the total response time, including the time required for fault isolation and the repair of the malfunctioned subsystem.

EFFECTS OF MODE OF OPERATION ON RESPONSE TIME

The malfunction or failures of subsystems can be grouped into two classes:

(i) "Emergency" situations which require immediate evacuation of a habitable space, and

(ii) "Danger" situations where there is no immediate threat to the crew safety, but corrective actions are required.

Typical response procedures in case of a subsystem failure are shown in Figure 8.

In view of the fact that the time required to arouse a person from sleep is just a few seconds, there would be very little difference in response times in a class I failure with respect to the mode of operation.

When a class II failure occurs, the responsive actions of the crewmen can be grouped into 3 phases:

(1) To get to a control console.

(2) Data analysis.

(3) Fault isolation and repair (Class IIa) or Evacuation (Class IIb).

The response time of phase 1 actions is affected both by the design of the spacecraft and the human reaction time which in turn might be greatly influenced by the choice of the mode of operation. The time required for phase 2 responses is primarily governed by the design of the instrument system, and, to a lesser extent, by the human reaction time. The time involved in fault isolation and repair in phase 3 is mainly controlled by the design of the test subsystem as well as the maintainability of the spacecraft; only a small effect, if any, could be brought about by the choice of mode of operation. It should be noted here that the evacuation which is required in Class IIb cases is classified as non-catastrophic, that is to say, ample response time would be allowed to perform this evacuation task; for a catastrophic failure indication will activate the "Emergency" alarm automatically at any time.

Since the actual response time required for data analysis, fault isolation, replacement or repair is so much dependent upon the design of the instrument systems it seems to be impossible to make an accurate quantitative evaluation of the effect of mode. However, based on the general conclusions drawn from the human behavior studies, as discussed in the previous sections, the relative response times required under each of the three modes of operation can be estimated simply by comparison.

The relative working efficiency of the crew members under three selected operational modes can be expressed graphically as shown in Figure 9. (The efficiency of an alert mode is assumed to have a value of 1 at all times.) Under a watch mode of operation, the working efficiency of the operator could be as low as 80% of the normal alert state at the time when the alarm is sounded because the operator might be in a state of incipient sleep. It is assumed that a five minutes period is needed for a full recovery. Under a sleep mode of operation, the efficiency is about 33% at the end of the first 10 seconds immediately following the arousal from sleep. It would reach 80% level in

60 seconds, and is idealized to stay at that level until 10 minutes has past. Then, a linear increase of efficiency is assumed by which a full recovery would be reached in 20 minutes after arousal from sleep.

By applying the efficiency evolution given by Figure 9, the relative solution times of a subsystem failure for each of the three modes of operation can be plotted against the normal solution time as shown in Figure 10. The normal solution time here is defined as the total response time required when the operator is fully alert and is on watch at the display panel at all times. In either an alert or sleep mode of operation, the time required by a crewman to get to the control console and begin a failure analysis is assumed to be 60 seconds. Under these assumptions, the curves given by Figure 10 show that, while the watch mode of operation requires the smallest total solution time, the penalty to be paid by choosing an alert mode of operation is very small. The delay of repair caused by the selection of the latter is about one minute which occurs only when the total normal solution time required is less than 5 minutes. For a longer normal solution time, the maximum difference between an alert mode and a watch mode is only 30 seconds. The sleep mode requires the longest solution time as expected, which is about 1 to 3 1/2 minutes longer than that required under a watch mode, depending upon the length of normal solution time as can be seen in the Figure.

CONCLUDING REMARKS

The analyses presented in the previous sections show that:

(1) With the warning system and storm shelter design as assumed, there is no significant difference among the three modes of operation considered so far as the safety of the crew members is concerned. In case of emergency, the time required to enter a storm shelter between a crewman who is awake and one being awakened from sleep will differ by only a few seconds.

(2) There is very little advantage of the watch mode of operation over the alert mode of operation so far as the response time is concerned, except in cases in which the total solution time required for a subsystem failure is very short and a delay of 60 seconds would seriously effect the repariability of the subsystem, and hence,

jeopardize the mission success.

(3) The penalty paid on response time by choosing a sleep mode of operation is slightly larger than the alert mode. But, this disadvantage may very well be offset by the possible savings on crew requirements. The crucial point is whether the possible 3 1/2 minutes delay can be tolerated without taking serious risk.

Previous studies[16,17] indicated that in a long duration, near earth orbit mission, the average repair time required for subsystem failures is more than one hour. Two examples of the repair task time estimated by North American Rockwell Corporation and the Boeing Company are shown in Figures 11 and 12, respectively. Since 3 1/2 minutes is only a small fraction of an hour, it is felt that a delay in that order would not be vital in most cases of non-catastrophic subsystem failures.

There are, however, a number of fundamental problems requiring investigation before any definite conclusions on the choice of spacecraft mode of operations can be made. These problems, among others, are:

1. What is the probability of unpredictable failures that cannot be preprogrammed and detected by machine? When such an unpredictable occurs, what is man's ability to respond in order to enhance the crew safety and mission success?

2. What are the number and nature of the predicted hazards that cannot be detected by machine, but are revealed only by man's unique capability of exercising judgement?

3. What are the possible subsystem failures for which only a few minutes of delay in corrective action could endanger crew survival and/or mission success?

4. Are complete, built-in test systems, including that of automatic fault-isolation feasible in the near future?

Needless to say that more extensive studies are apparently needed to answer these important questions. However, a few remarks can be drawn tentatively, by using the results of the present study:

1. The watch mode of operation does not seem to offer any significant advantage over the other two modes considered during the normal cruising phase of a long-duration flight.

2. The alert mode of operation appears to be a reasonable choice for the basic mode of operation.

3. It is highly probable that a sleep mode can be applied without great sacrifice on the crew safety and/or mission success.

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C. C. Ong

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Attachments

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TABLE 1

COMPARISON OF MODES OF OPERATION

MODE OF OPERATION	NO. OF CREWMEN TRAINED FOR SPACECRAFT OPERATION	NO. OF CREWMEN SCHEDULED FOR OPERATION	FREEDOM TO EVOLVE OPERATOR'S WORK/REST SCHEDULE	INTERACTION WITH EXPERIMENTS
Sleep	1 Commander 1 Backup Total 2	1	Almost Complete Freedom	Little
Alert	1 Commander 2 Backups Total 3	1	Limited Freedom	Complex
Watch	1 Commander 2 Deputy Commanders 1 Backup Total 4	3	Very Little Freedom	None

TABLE 2

SIMPLE REACTION TIME (TAKEN FROM REF. 5)

STIMULUS	REACTION TIME - SECONDS	
	MEAN	RANGE
Sound	0.20	0.12~0.45
Touch	0.20	0.12~0.45
Light	0.30	0.15~0.50

TABLE 3

COMPLEX REACTION TIME (TAKEN FROM REF. 5)

NUMBER OF CHOICES	APPROXIMATE MEAN REACTION TIME (sec.)
1	0.20
2	0.35
3	0.40
4	0.45
5	0.50
6	0.55
7	0.60
8	0.60
9	0.65
10	0.65

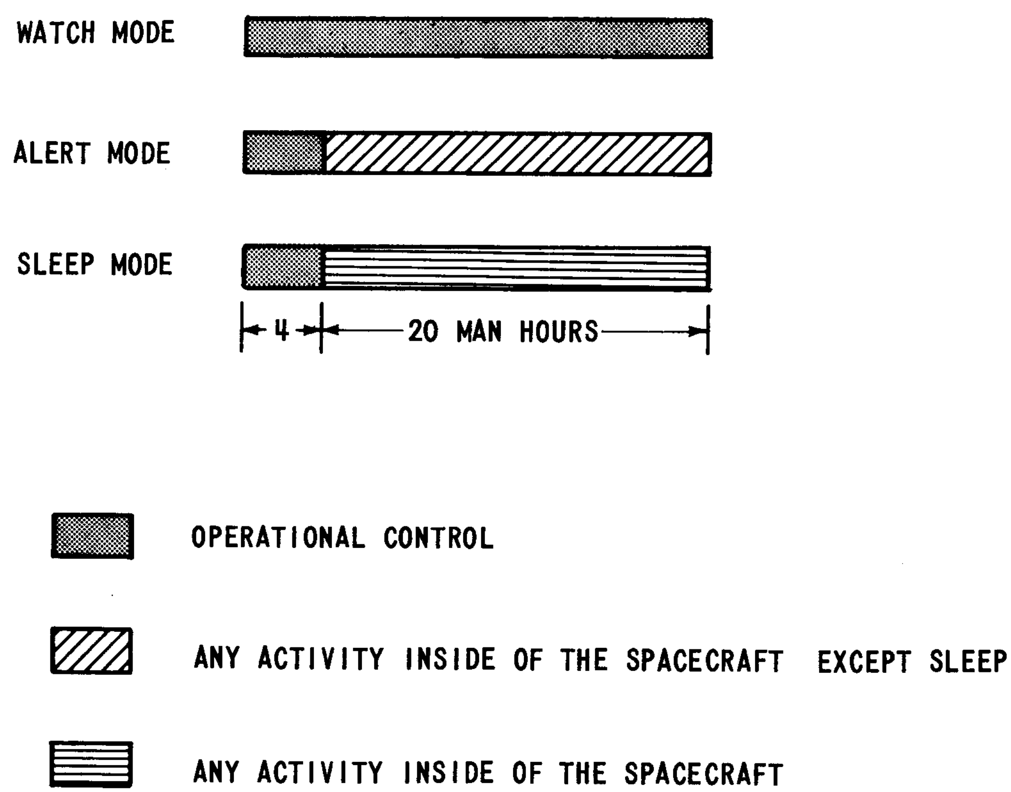


FIGURE 1 - COMPARISON OF TIME REQUIREMENT FOR OPERATIONAL CONTROL

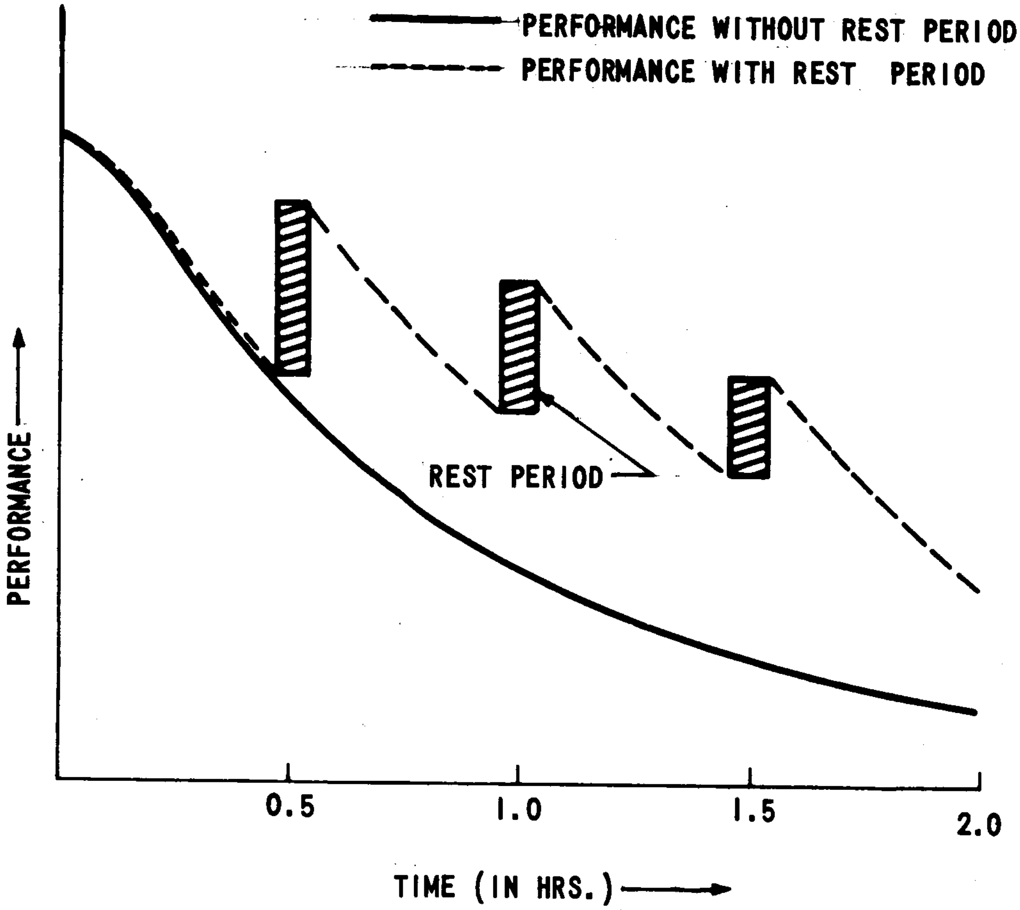


FIGURE 2 - PERFORMANCE ON A DIFFICULT VIGILANCE TASK WITH AND WITHOUT REST PERIODS (TAKEN FROM REF. 6)

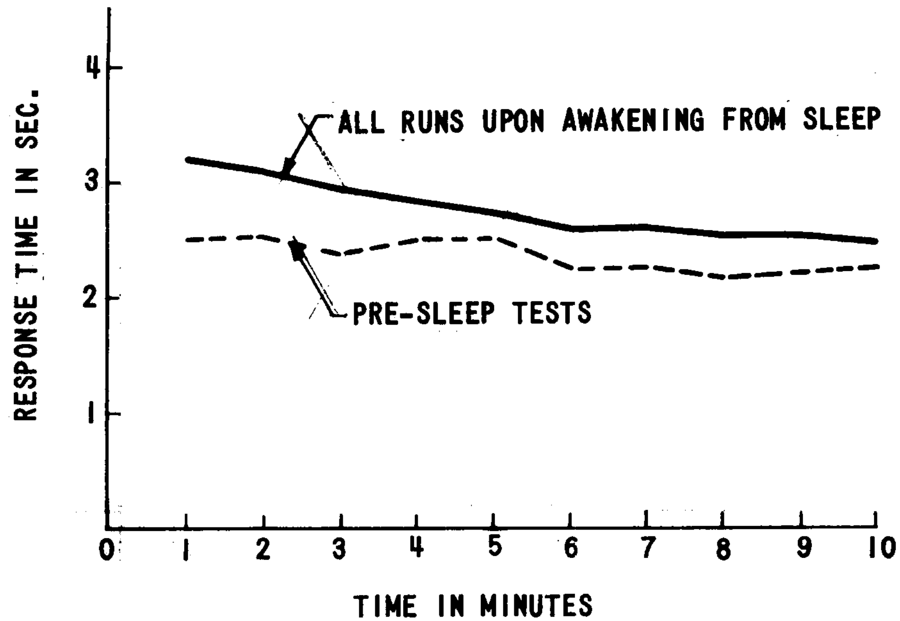


FIGURE 3 - COMPARISON OF MEAN RESPONSE TIMES BEFORE SLEEP AND AFTER AWAKENING FROM SLEEP (TAKEN FROM REF. 9)

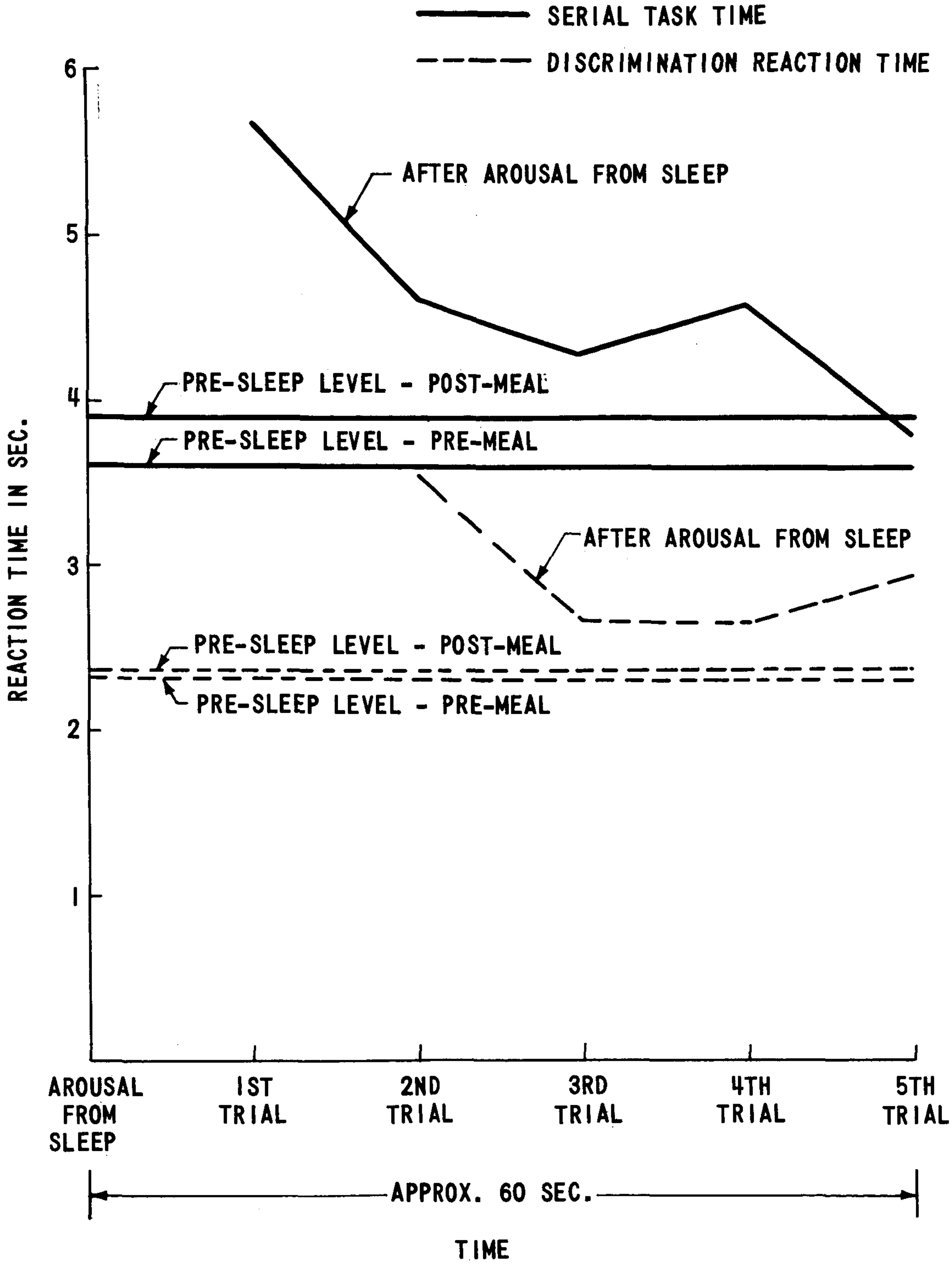
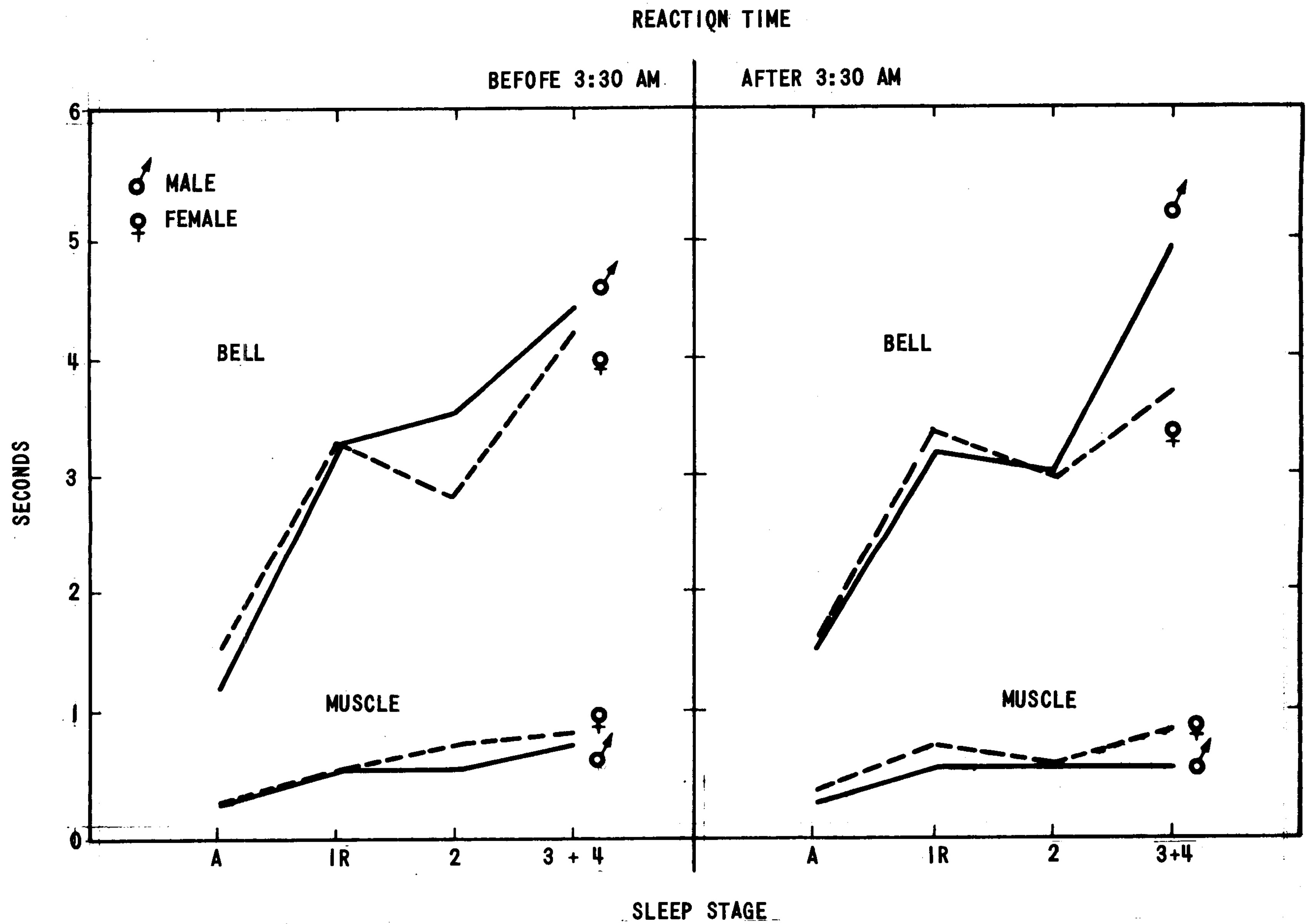


FIGURE 4 - REACTION TIME AFTER BEING AROUSED FROM AN AFTERNOON SLEEP (BASED ON DATA TAKEN FROM REF. 11)



NOTE: (1) THE LEVEL OF SLEEP IS DEFINED BY THE PATTERN OF BRAIN WAVES IN THE ELECTROENCEPHALOGRAM (EEG) RECORDS.

(2) "A" INDICATES AWAKE; "IR" INDICATES STAGE I SLEEP WITH RAPID EYE-MOVEMENTS, I.E., DREAMING.

(3) HIGHER NUMBER INDICATES LOWER FREQUENCY AND HIGHER AMPLITUDE EEG WAVES, I.E., DEEPER SLEEP.

FIGURE 5 - REACTION TIME IMMEDIATELY AFTER AWAKENING FROM SLEEP
(PREPARED BY J. SCOTT OF NIH)

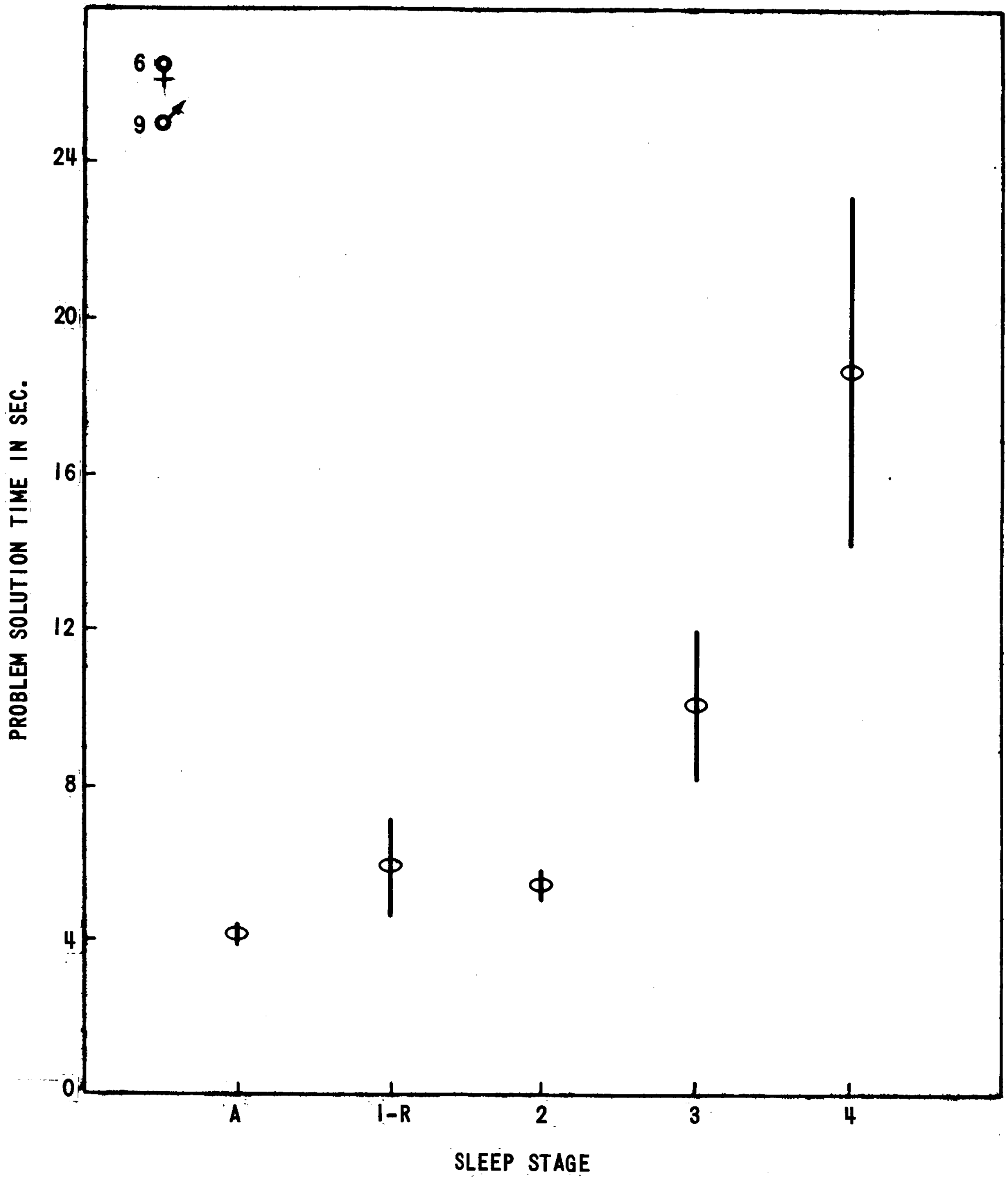


FIGURE 6 - PROBLEM SOLUTION TIME IMMEDIATELY AFTER AWAKENING FROM SLEEP (PREPARED BY J. SCOTT OF NIH)

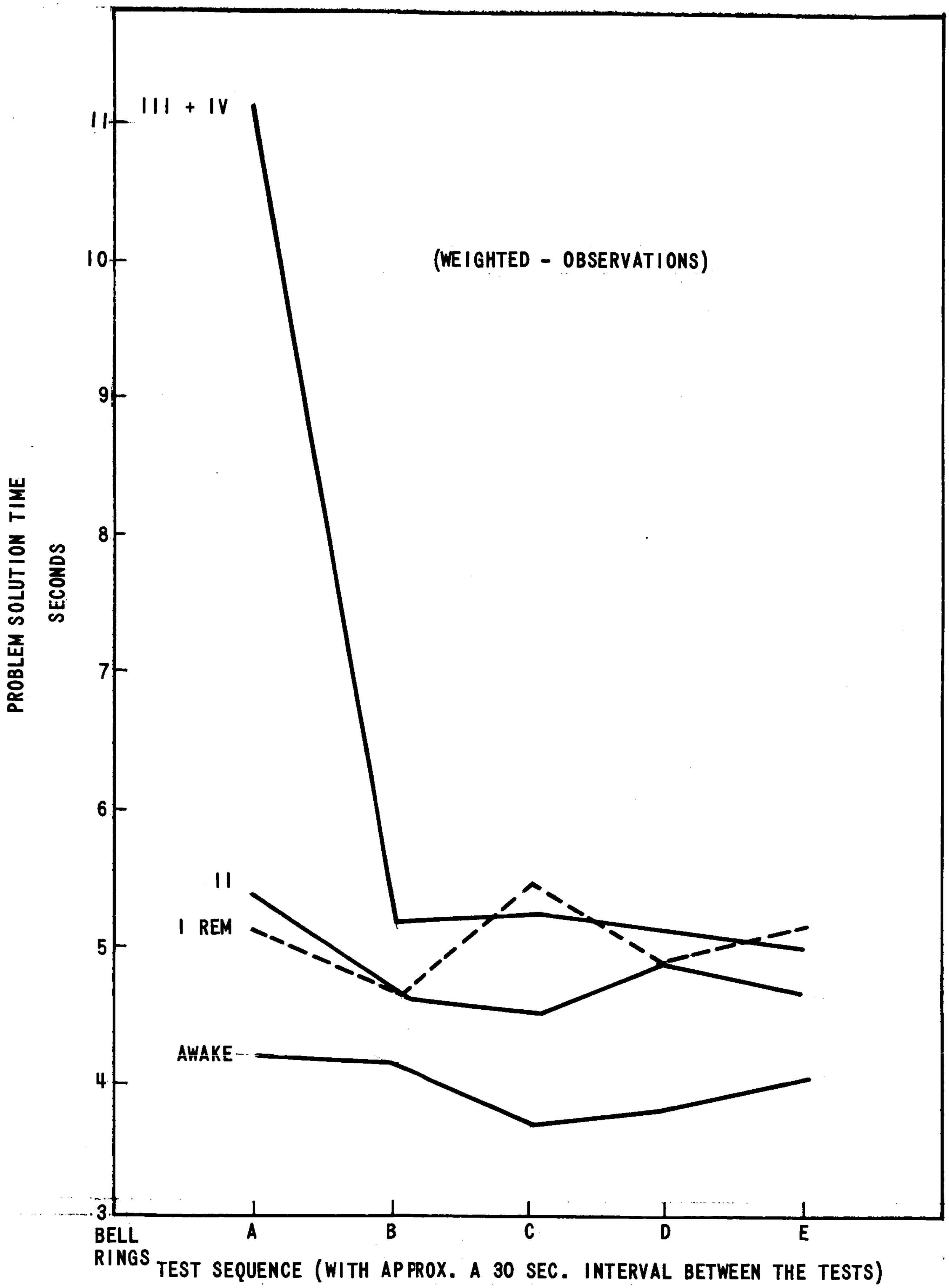


FIGURE 7 - RECOVERY PROCESS OF PROBLEM SOLUTION TIME
(PREPARED BY J. SCOTT OF NIH)

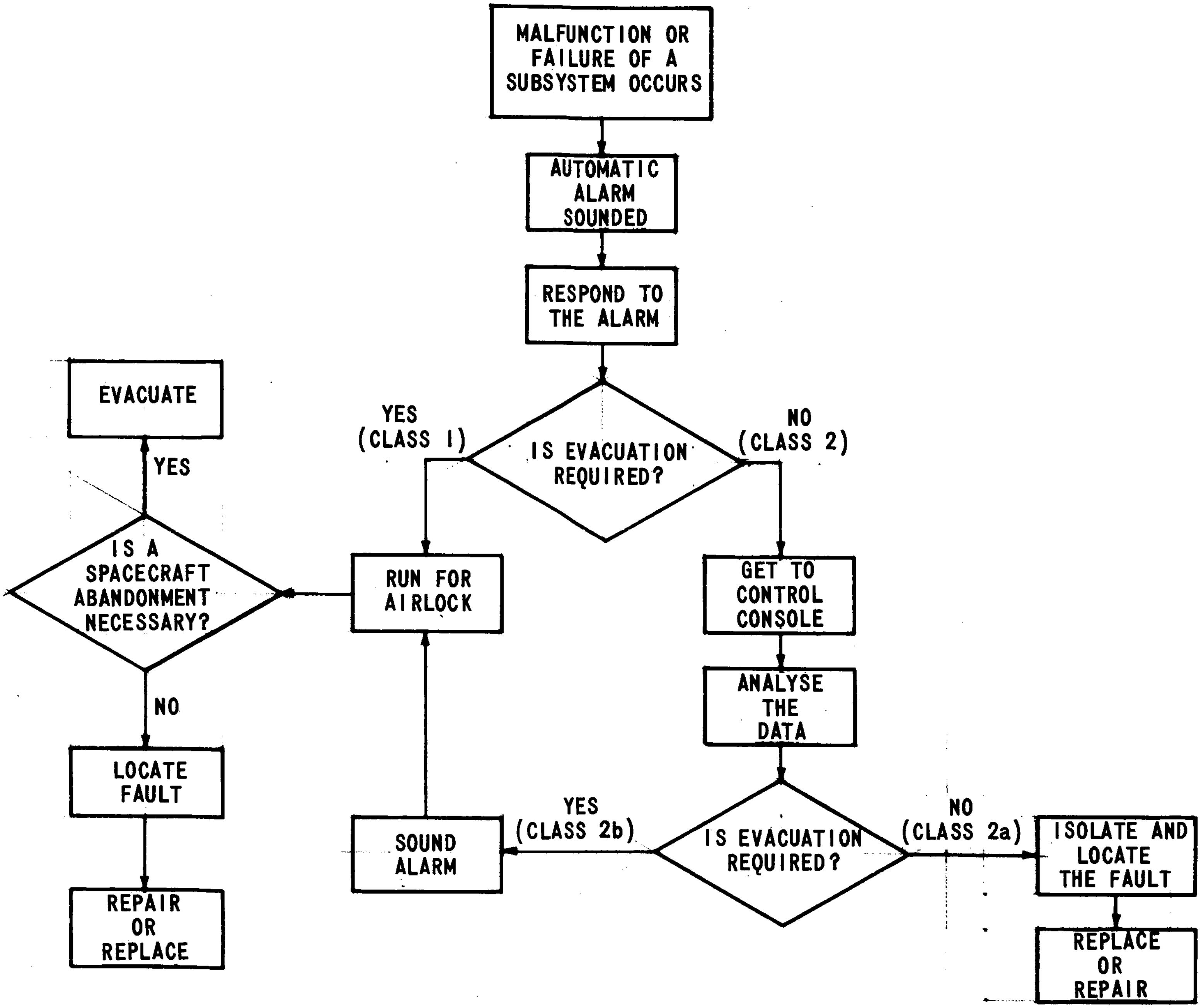


FIGURE 8 - RESPONSE PROCEDURE TO A SUBSYSTEM FAILURE

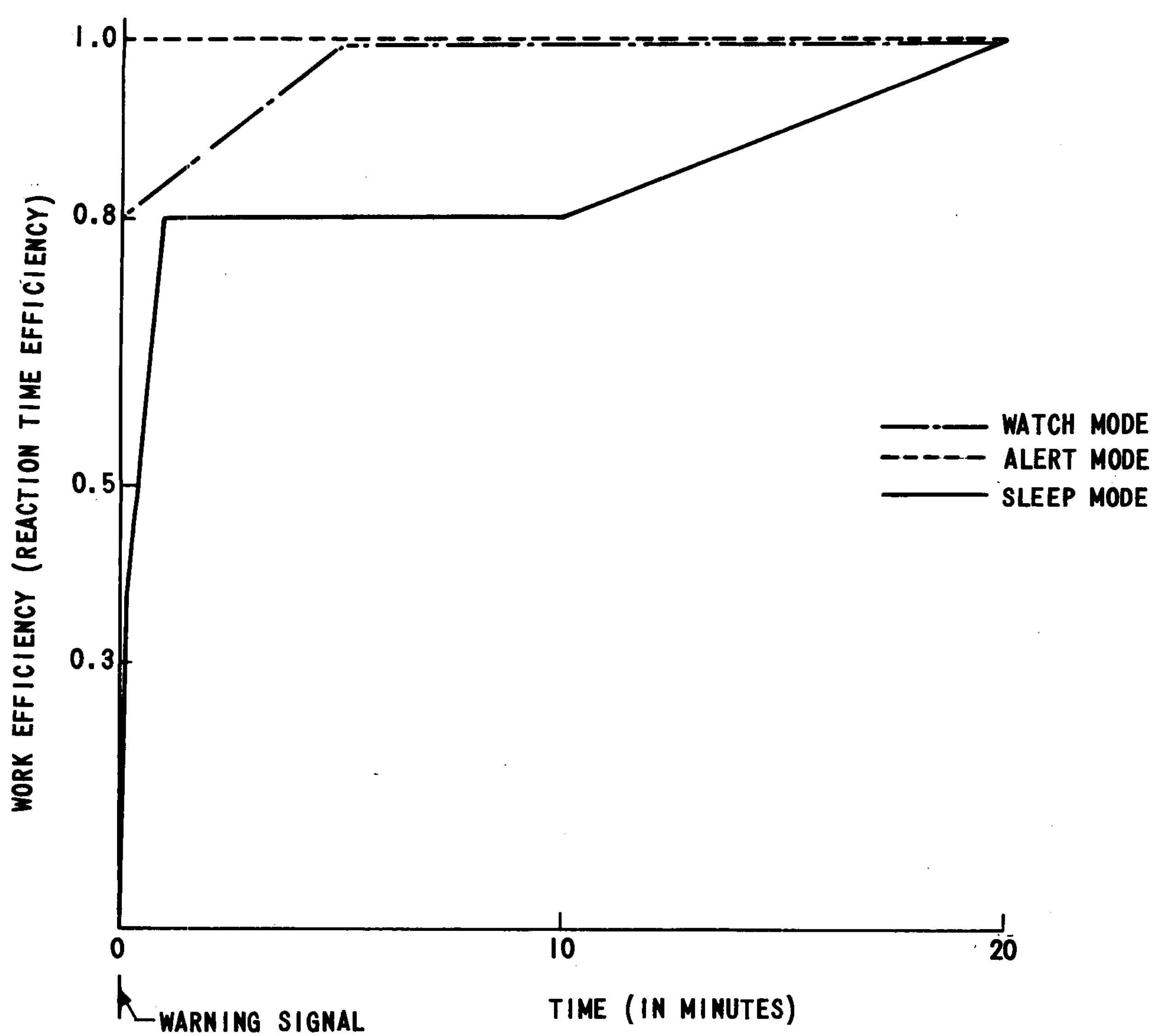


FIGURE 9 - WORK EFFICIENCY

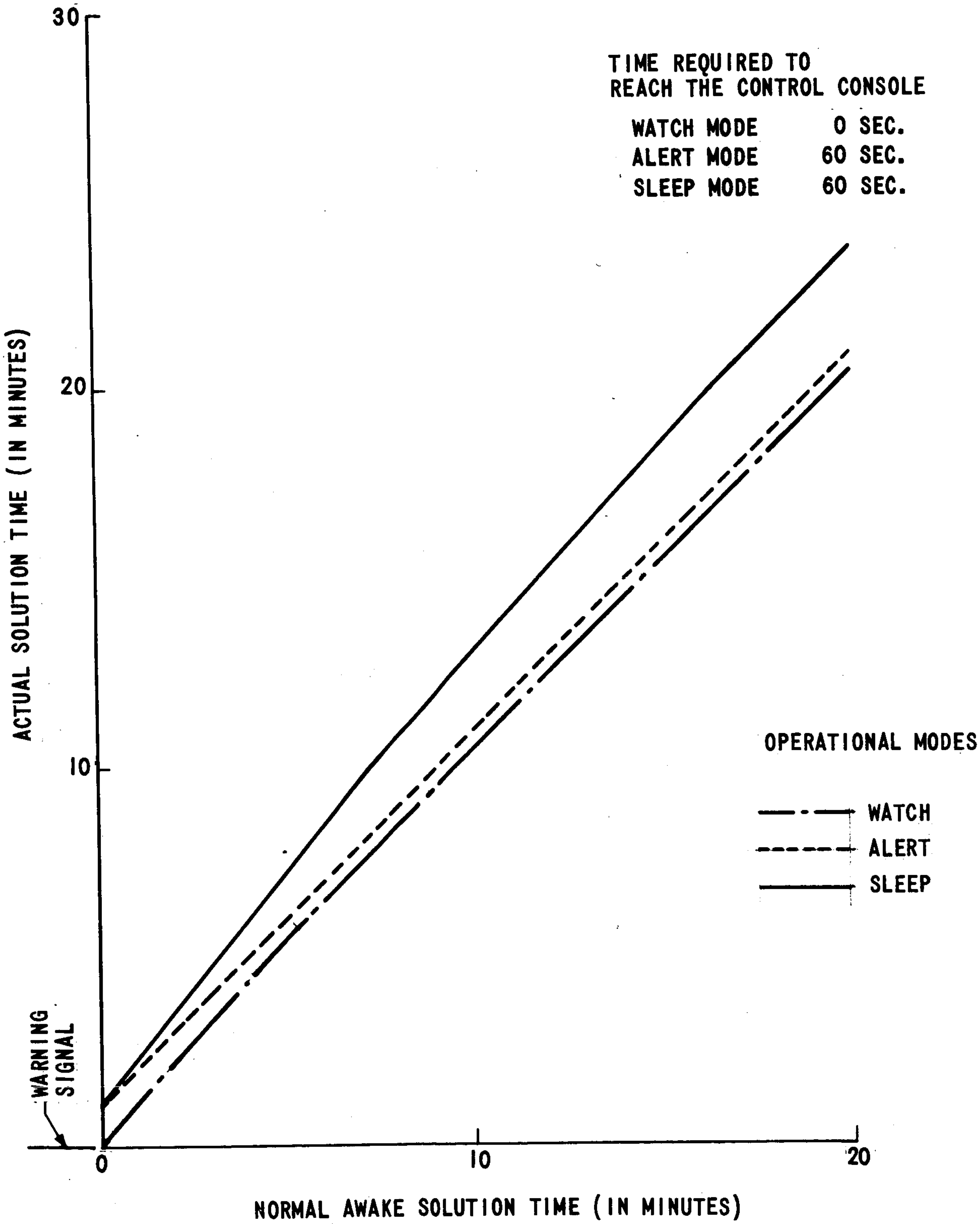


FIGURE 10 - SOLUTION TIME OF MALFUNCTIONS

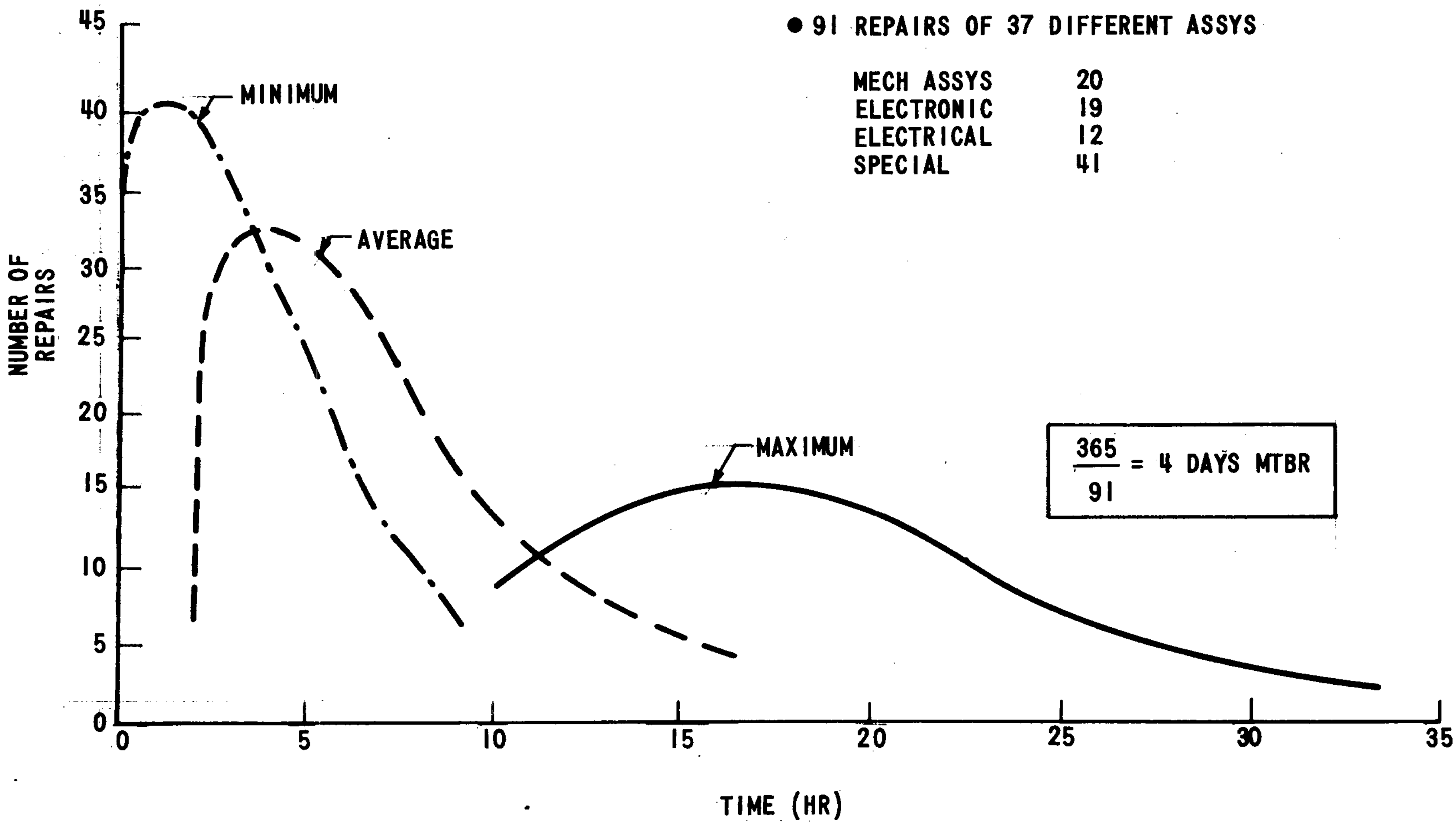


FIGURE 11 - REPAIR TIME FOR LONG-DURATION EARTH ORBIT MISSION
(TAKEN FROM REF. 16)

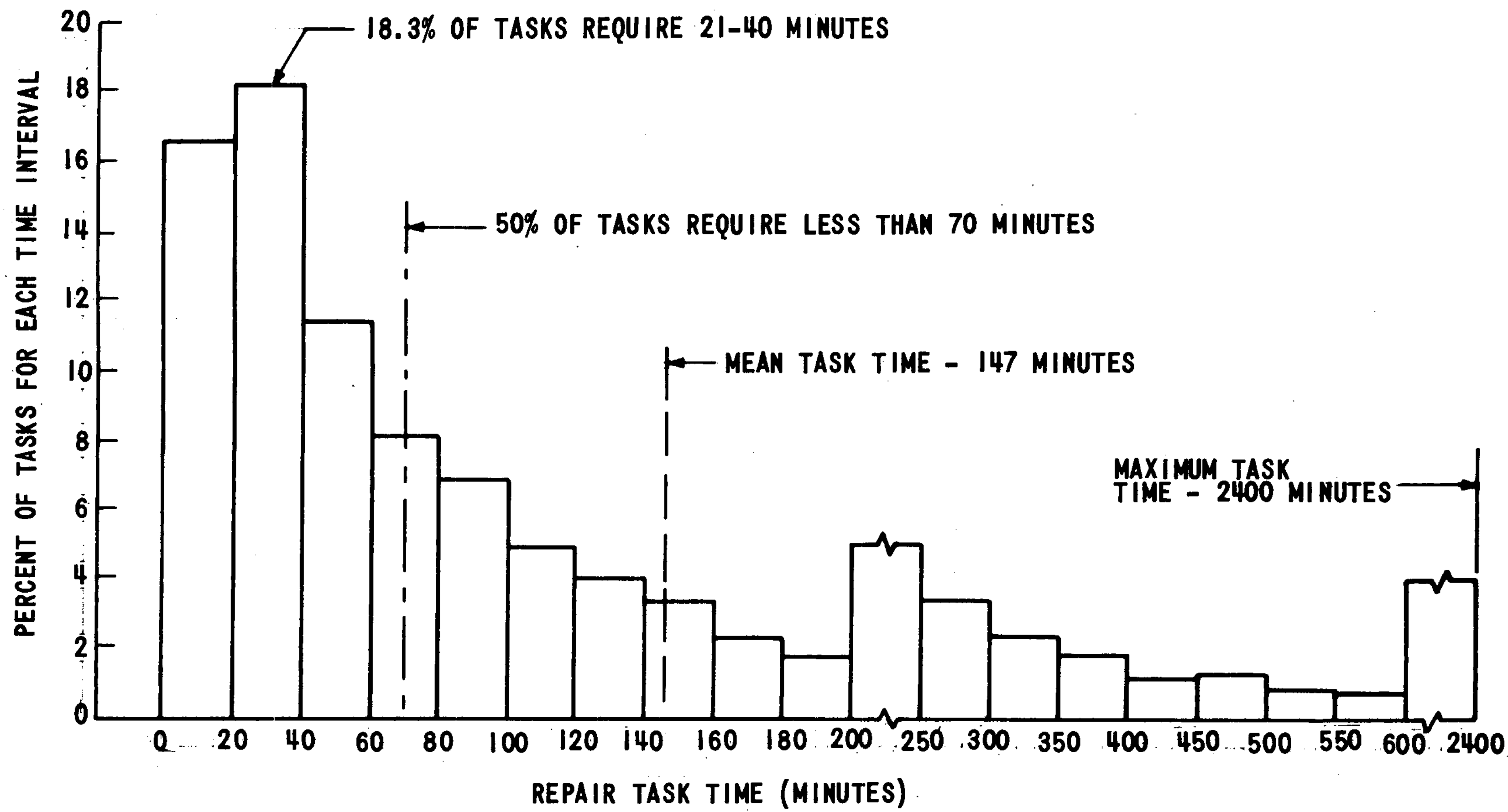


FIGURE 12 - UNSCHEDULED MAINTENANCE REPAIR TASK TIME DISTRIBUTION - 1975 NEAR-EARTH ORBIT MISSION (TAKEN FROM REF. 17)